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SHATTERING, BREAKING AND THRESHABILITY IN BARLEY VARIETIES[1]

A. W. Platt and S. A. Wells[2]

Dominion Experimental Station, Lethbridge, Alberta

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INTRODUCTION

Shattering and breaking in barley have always caused important losses to growers in the open plains region of Western Canada. This damage is caused by wind or by wind and rain as the crop nears maturity or after it matures. The straw may be broken over, the spike broken off or the seed lost from the spike. Such damage has no relation to lodging. Formerly these losses were not so important because acreages of barley were small and it was all harvested with binders at or just before maturity. Under such conditions it was only in the occasional field that serious losses occurred. However, for a number of years much larger acreages have been grown and practically all the crop has been harvested with combines. As the crop must be thoroughly mature and dry before this method of harvesting is successful, it has been exposed to damage, often for periods of several weeks, at a time when it is very susceptible. Swathing the crop to avert damage has reduced losses in most cases. However, light crops cannot be swathed satisfactorily as difficulty is experienced in picking up thin swaths. Moreover, losses still occur because large acreages cannot be readily covered in a short period of time.

Observations on shattering and breaking in barley were commenced at Swift Current Experimental Station in 1942. In that year extensive damage occurred to the varietal test plots. It was noted that different types of damage occurred and that varietal differences existed. Since that year notes on the various types of damage that occurred to each variety in test plots have been taken each year. The object was to determine the different types of damage, something of the factors affecting damage and, more particularly, the best sources of resistance that might be used in a breeding program.

Recently the variety Titan has become available for commercial production. It has high resistance to shattering and breaking. Unfortunately, in commercial production this variety was found difficult to thresh, which suggested the possibility that in breeding for resistance to shattering a problem in threshing might arise. Accordingly, attempts were made to evaluate the threshability of varieties and to relate this to their tendency to shatter.

This whole study was necessarily of an exploratory nature, but the information obtained should be of value in planning more precise experiments.

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[2] Formerly Cerealist-in-Charge, and Assistant Cerealist, respectively, Dominion Experimental Station, Swift Current; now Cerealist-in-Charge and Coarse Grains Specialist, Cereal Breeding Laboratory, Dominion Experimental Station, Lethbridge.

TYPES OF DAMAGE

The terminology used to describe damage to cereal crops caused by weather conditions from the time the crop nears maturity until it is harvested does not appear to be well established. Accordingly, the terms used in this paper are defined below. They appear to be reasonably suitable when applied to barley and may or may not have application to other crops.

Shattering—refers to loss of seed from the spike. In these experiments all such losses were classified as shattering loss. It has recently been observed, however, that such losses occur two ways. In the first, individual seeds become detached from the rachis and fall to the ground. This damage is characteristic of the varieties Prospect and Bay. In future experiments it is proposed to reserve the term "shattering" for this type of damage. In the second type the rachis breaks and part of the spike is lost. This is characteristic of the variety Warrior. It is proposed, in future experiments, to refer to this as "rachis breaking".

Damage to the straw has been classified into three types.

Neck breaking—refers to a break in the upper internode, almost always near the spike, with the spike usually falling to the ground or, occasionally, hanging down the side of the stem.

Stem breaking—refers to definite breaks in the stem at any point below the upper internode. Such damage has been observed only following prolonged winds of high velocity.

Buckling—refers to a bending or partial breaking, usually at a number of points in the stem. In extreme cases the spike may touch the ground but does not become detached from the stem. The term "buckling" was used because it describes a condition similar to that occurring in wheat and described by Fellows (3) as "buckling". Various authors have referred to "crinkling" in small grains, and in some cases they may have had in mind the condition described above.

METHODS

The data obtained were taken on the border rows of the regular varietal tests. The varieties were grown in three rod-row plots replicated six times. Data from the dryland tests were obtained in each of the years 1943 to 1947. In all of those years the crop suffered considerably from drought. During the years 1945 to 1947, data were also obtained from the varietal tests grown under irrigation. Compared with the dryland tests those irrigated were under different soil and moisture conditions but were subjected to approximately the same weather conditions at all times.

On the average, the data were taken about two weeks after the latest variety in the test had matured. Following the harvesting of the centre row the borders were kept under observation, and when a good differential was evident the notes were taken. In some years this occurred at maturity and in others almost a month might have elapsed. Notes on all varieties were taken on the same day. Hence, early-maturing varieties were exposed to damage for a longer period than late ones. While this was undoubtedly a source of error in evaluating varietal reaction, it appeared to be small in

relation to the differences between varieties. In fact, the most highly resistant varieties were among the earliest in the tests. As the notes were not taken until a differential occurred, the values obtained are in excess of normal field losses by substantial amounts. Field losses as great as any reported do occur, however, when the crop is not harvested promptly or when unfavourable weather intervenes.

In evaluating shattering, the percentage of seeds lost from the spike was estimated. No attempt was made to differentiate between losses due to the seeds becoming detached from the rachis and losses due to rachis breaking. It was not realized until recently that the type as well as the amount of shattering might be a varietal characteristic. Neck breaking and stem breaking were evaluated either by making counts or by estimating the percentage broken. When estimating shattering or breaking, the mean of two independent estimates was used in practically all cases. No attempt was made to assign numerical values to buckling damage that occurred.

In evaluating ease of threshing, the samples from the centre rows of the plots were air-dried and then threshed in a Kemp thresher. This machine has been described by Kemp (6). In 1946, lots of one hundred seeds each were taken from each of three replicates. The percentage of threshed and unthreshed seed was noted. A seed was considered unthreshed if more than 3 mm. of awn remained or if any of the rachis was adhering. Since there was no evidence of any significant variation due to replicates in this test, lots of one hundred seeds each were taken from a bulk sample from the six replicates in 1947. This test was conducted for only the two years and only on the dryland samples.

In analysing the data Goulden (4) has been used as a guide. As the values obtained were percentage figures and as zero readings were sometimes obtained, the value "1" was added to all readings and these were then converted to $\sin^2\theta$. To establish the significance of varietal differences the results of each test were analysed by variance. It was not possible to group the tests because the varieties differed from year to year. The inter-relationships of the various characters were studied by means of covariance except for the data on threshability. As these data were not taken on individual plots the covariance technique was not applicable. In this case the correlation coefficient was used.

SHATTERING

Some of the statistics calculated from the data on shattering are presented in Table 1. In all tests highly significant varietal differences were established. In most tests the magnitude of the differences was substantial, indicating that they are of importance in evaluating varieties for commercial production.

Eight varieties were grown on both irrigated and dryland for the three years 1945-47. The average percentage shattering for these varieties in both locations is presented in Table 2. Shattering on irrigated land was much greater than on dryland. Only one of the varieties shattered appreciably on dryland whereas only one showed high resistance to shattering on irrigated land.

A summary of results obtained with a number of named varieties grown on dryland is presented in Table 3 and with some grown on irrigated land in Table 4. The variety Glacier was outstanding in that it was resistant in all tests. Such varieties as Titan and Trebi were highly resistant in the dryland tests but showed some susceptibility in the irrigated tests. Warrior was resistant in some tests on dryland and susceptible in others. It was not tested under irrigation. Montcalm and O.A.C. 21 were susceptible in all tests in which they were included. Prospect was also highly susceptible to shattering.

TABLE 1.—MEAN PER CENT SHATTERING AND RANGE OF SHATTERING AMONG BARLEY VARIETIES GROWN ON DRYLAND, 1943-1947, AND ON IRRIGATED LAND, 1945-1947, TOGETHER WITH CONVERTED DATA ($n + 1 = \sin^2\theta$) AND STANDARD ERRORS AND F VALUES CALCULATED FROM THE CONVERTED DATA

Year	No. of vars.	Mean		S.E. in per cent	Min. sig. diff.	Range (actual)		Range (converted)		F[1]
		Actual	Converted			Low	High	Low	High	
Grown on dryland										
1943	17	7.0	14.1	7.38	2.9	1.5	15.0	7.1	23.2	30.47
1944	26	9.3	16.8	13.08	6.2	0.0	34.1	5.7	36.2	11.85
1945	49	7.1	14.4	13.96	5.6	0.0	42.5	5.7	41.2	13.38
1946	42	12.5	18.3	17.50	8.9	0.0	49.2	5.7	45.0	12.82
1947	36	19.1	22.7	11.41	7.2	0.0	77.5	5.7	62.8	40.15
Grown on irrigated land										
1945	36	18.3	21.6	14.97	9.1	0.0	67.5	5.7	56.6	26.08
1946	28	8.9	15.5	13.40	5.8	0.0	50.8	5.7	46.0	25.14
1947	30	13.0	18.7	14.76	7.7	0.0	50.8	5.7	46.1	17.22

[1] All F values exceed the 1 per cent point.

Because different varieties were included each year it is not possible to use the data in Table 1 for evaluating the effect of years. The results in Tables 3 and 4 show clearly, however, that the amount of shattering varies from year to year on both irrigated and dryland. This is in line with general farm experience. Two main factors appear to be involved. The first of these has to do with the condition of the crop. If the crop matures normally so that large plump kernels are produced, it seems to be particularly susceptible to shattering. On the other hand, if drought intervenes and the crop ripens prematurely with shrunken kernels, it is highly resistant to shattering. The second factor is weather conditions, particularly wind, at the time the crop is ripe. The interactions of these two factors largely determine the amount of shattering that occurs. Thus, in the dryland test in 1943 the crop was subjected to severe drought and little wind was experienced during the harvesting period, with the result that very little shattering was experienced. On the other hand, in 1947, the irrigated test was subjected to severe winds and, as drought was not a factor, shattering was very severe.

TABLE 2.—AVERAGE PER CENT SHATTERING, 1945-1947, FOR VARIETIES GROWN ON IRRIGATED AND DRY LAND

Variety	Per cent shattering, 1945-1947	
	Irrigated	Dry
Glacier	1.7	0.1
Hybrid 36-1991	5.3	0.3
Velvon	15.0	1.0
Vantage	15.7	1.3
Trebi	16.1	1.6
Titan	17.1	0.7
Plush	20.5	4.2
Newal	34.1	19.2
Average	15.7	3.6

TABLE 3.—PER CENT SHATTERING IN BARLEY VARIETIES GROWN ON DRYLAND AT SWIFT CURRENT, 1943-1947

Variety	C.A.N.	Per cent shattering						
		1943	1944	1945	1946	1947	Av. 5 yr.	Av. 3 yr.
Glacier	1149	0.7	0.0	0.2	0.0	0.0	0.2	0.1
Titan	1164	1.5	2.3	0.2	0.8	1.2	1.2	0.7
Trebi	1115	2.2	2.3	1.5	1.7	1.7	1.9	1.6
Plush	1117	2.7	3.1	1.7	4.2	6.7	3.7	4.2
Rex	1113	1.8	9.5	3.2	4.2	14.2	6.6	7.2
Newal	1089	8.2	7.0	8.5	10.0	39.2	14.6	19.2
Warrior	1144	2.3	9.5	8.5	10.8	50.8	16.4	23.4
Montcalm	1135	12.0	12.8	15.3	20.0	37.5	19.5	24.3
Prospect	1140	5.0	30.0	15.0	45.0	29.2	23.9	29.7
Atlas	702	—	—	1.3	0.8	0.0	—	0.7
Compana	1154	—	—	1.8	0.0	0.8	—	0.9
Vance Smyrna	—	—	—	1.3	0.8	0.8	—	1.0
Vantage	1162	—	—	0.6	1.7	1.6	—	1.3
Tregal	1150	—	—	4.3	7.5	12.5	—	8.1
O.A.C. 21	1086	—	—	17.2	44.2	19.2	—	26.9

TABLE 4.—PER CENT SHATTERING IN BARLEY VARIETIES GROWN ON IRRIGATED LAND AT SWIFT CURRENT, 1945-1947

Variety	C.A.N.	Per cent shattering			
		1945	1946	1947	Average
Frontier	110	0.3	0.8	1.7	0.9
Glacier	1149	2.5	0.0	2.5	1.7
Lico	1152	4.7	11.7	20.0	12.1
Sanalta	1088	26.7	5.0	8.3	13.3
Velvon No. 11	1151	7.5	15.8	21.7	15.0
Vantage	1162	10.5	13.3	23.3	15.7
Trebi	1115	9.2	10.0	29.2	16.1
Titan	1164	13.0	15.8	22.5	17.1
Plush	1117	13.0	16.7	31.7	20.5
Newal	1089	28.0	24.2	50.0	34.1

NECK BREAKING

Some of the statistics calculated from the data on neck breaking are presented in Table 5. As was the case in the shattering test, highly significant varietal differences were established in all tests and these differences were of sufficient magnitude to be of economic importance.

Mean values for the percentage neck breaking for the eight varieties common to the irrigated land and dryland tests for the three years are presented in Table 6. Unfortunately, all these varieties, except Newal, are quite resistant to neck breaking so that a comparison of irrigated and dryland results is difficult to make. The evidence available suggests that, in contrast to shattering, breaking is more likely to occur under dryland conditions.

A summary of results obtained with a number of named varieties grown on dryland is presented in Table 7 and with some grown on irrigated land in Table 8. Glacier was highly resistant in all tests. The Manchurian types as a group appear to be very susceptible. No variety of this type has been found to have a high degree of resistance. Differences within the group do occur, however; O.A.C. 21 appears to be the most susceptible whereas Montcalm is somewhat more resistant. Newal and Tregal are two other varieties that show considerable susceptibility to neck breaking.

TABLE 5.—MEAN PER CENT NECK BREAKING AND RANGE OF NECK BREAKING AMONG BARLEY VARIETIES GROWN ON DRYLAND, 1943-1947, AND ON IRRIGATED LAND, 1945-1947, TOGETHER WITH CONVERTED DATA ($n + 1 = \sin^2\theta$) AND STANDARD ERRORS AND F VALUES CALCULATED FROM THE CONVERTED DATA

Year	No. of vars.	Mean		S.E. in per cent	Min. sig. diff.	Range (actual)		Range (converted)		F[1]
		Actual	Converted			Low	High	Low	High	
Grown on dryland										
1943	17	33.5	34.7	9.21	9.21	7.8	81.7	15.6	65.9	36.81
1944	26	21.1	26.4	14.40	10.64	2.5	43.0	10.2	41.1	5.94
1945	49	13.7	20.7	11.72	6.77	0.0	46.6	5.7	43.4	12.71
1946	42	7.3	14.7	16.70	6.82	0.0	27.5	5.7	32.3	8.42
1947	36	20.9	24.8	14.65	10.16	0.0	74.2	5.7	60.6	16.82
Grown on irrigated land										
1945	36	5.8	13.5	15.70	5.94	0.0	15.0	5.7	23.1	6.41
1946	28	1.9	8.7	20.28	4.93	0.0	6.7	5.7	15.2	2.31
1947	30	4.6	11.6	23.75	7.70	0.0	33.3	5.7	33.9	3.69

[1] All F values exceed the 1 per cent point.

In considering the effect of environment on neck breaking it appears that premature ripening of the crop predisposes it to damage. This is in direct contrast to shattering. If the crop is in this condition there is usually sufficient wind to cause substantial damage in susceptible varieties. Under favourable growing conditions, on the other hand, relatively little damage may be experienced on susceptible varieties even when exposed to severe winds. An example of this occurred in the 1947 irrigated test when Newal was damaged only 5 per cent even though it was severely battered with strong winds.

TABLE 6.—AVERAGE PER CENT NECK BREAKING, 1945-1947, FOR VARIETIES GROWN ON IRRIGATED AND DRY LAND

Variety	Per cent neck breaking, 1945-1947	
	Irrigated	Dry
Glacier	1.2	0.7
Hybrid 36-1991	2.8	2.1
Trebi	8.3	3.9
Titan	3.9	5.4
Vantage	2.1	5.5
Velvon	4.2	6.1
Plush	5.3	9.6
Newal	7.5	16.4
Average	4.4	6.2

TABLE 7.—PER CENT NECK BREAKING IN BARLEY VARIETIES GROWN ON DRYLAND AT SWIFT CURRENT, 1943-1947

Variety	Per cent neck breaking						
	1943	1944	1945	1946	1947	Av. 5 yr.	Av. 3 yr.
Glacier	7.0	3.5	1.3	0.0	0.8	2.5	0.7
Warrior	9.3	6.8	1.0	4.2	12.5	6.8	5.9
Titan	11.2	11.3	7.8	2.5	5.8	7.7	5.4
Trebi	16.2	16.8	7.5	1.7	2.5	8.9	3.9
Prospect	12.5	14.5	10.8	2.5	8.3	9.7	7.2
Rex	10.2	17.6	13.3	5.0	5.8	10.4	8.0
Plush	17.5	19.5	11.3	4.2	13.3	13.2	9.6
Newal	39.2	41.5	16.6	11.7	20.8	26.0	16.4
Montcalm	50.0	25.7	36.7	6.7	35.0	30.8	26.1
Atlas	—	—	0.0	0.8	2.5	—	1.1
Vance Smyrna	—	—	5.8	0.0	1.6	—	2.5
Compana	—	—	9.1	0.8	1.7	—	3.9
Vantage	—	—	6.6	3.3	6.6	—	5.5
Tregal	—	—	12.5	6.7	38.3	—	19.2
O.A.C. 21	—	—	46.6	21.7	74.2	—	47.5

TABLE 8.—PER CENT NECK BREAKING IN BARLEY VARIETIES GROWN ON IRRIGATED LAND AT SWIFT CURRENT, 1945-1947

Variety	Per cent neck breaking			
	1945	1946	1947	Average
Glacier	0.3	0.8	2.5	1.2
Vantage	2.8	1.7	1.7	2.1
Lico	3.3	0.0	4.2	2.5
Titan	8.3	0.0	3.3	3.9
Frontier	9.7	2.5	0.0	4.1
Velvon No. 11	6.7	1.7	4.2	4.2
Plush	7.5	2.5	5.8	5.3
Newal	10.8	6.7	5.0	7.5
Trebi	14.2	3.3	7.5	8.3
Sanalta	14.2	15.0	7.5	12.2

STEM BREAKING

Data on stem breaking were secured on one test only. This was the 1947 test grown on dryland. Just as the majority of the varieties neared maturity they were subjected to a prolonged wind of high velocity. Data on the duration, direction and velocity by hour of this storm are presented in Table 10. A summary of the results obtained with some of the varieties in this test is presented in Table 9. Among the most resistant varieties were Bay, Glacier and Rex. The Manchurian types, particularly O.A.C. 21, were highly susceptible.

TABLE 9.—MEAN PER CENT STEM BREAKING AMONG BARLEY VARIETIES GROWN ON DRYLAND, 1947, TOGETHER WITH CONVERTED MEANS ($n + 1 = \sin^2\theta$)

Variety	Per cent stem breaking	
	Actual	Converted[1]
Rex	2.5	10.0
Prospect	4.2	11.5
Glacier	5.8	14.8
Trebi	8.3	16.1
Plush	13.3	19.6
Warrior	15.0	22.6
Newal	16.7	23.2
Titan	16.7	23.2
Vantage	21.6	27.4
Tregal	27.5	30.0
Compana	40.0	38.8
Vance Smyrna	46.6	43.3
O.A.C. 21	54.2	48.0
Atlas	63.3	53.8

[1] The minimum significant difference between converted variety means is 11.6.

BUCKLING

Among the common, named varieties of barley this type of damage has been observed only in Compana. A few types from the U.S.D.A. world's collection of barleys have also exhibited buckling. All varieties showing buckling have been short-strawed, two-rowed types. The condition became evident only after the varieties were well matured and became progressively worse with time. It does not appear to be directly due to weather conditions but rather to a deterioration and eventual collapse of culm tissue. As the phenomenon does not occur with equal intensity in all tests, it can be presumed that it is modified by environmental conditions. It appears to present no great hazard to commercial production if the crop can be harvested as soon as it is well matured, but heavy losses might occur if this were not possible.

THRESHABILITY

A summary of some of the threshing data is presented in Table 11. Analysis of the data from three replicates of the 1946 test on dryland showed no significant variation due to replicates. Accordingly, in 1947,

TABLE 10.—TOTAL MILES OF WIND PER HOUR PASSING A GIVEN POINT AT SWIFT CURRENT ON JULY 28 AND 29, 1947

(Data kindly provided by the Swift Current branch of the Dominion Meteorological Service)

Date	Time	Direction	Miles per hour
July 28	4 p.m.	S.W.	23
	5 p.m.	S.W.	26
	6 p.m.	W.	36
	7 p.m.	W.	40
	8 p.m.	W.	34
	9 p.m.	W.	28
	10 p.m.	W.	32
	11 p.m.	W.	30
	12 p.m.	W.	26
July 29	1 a.m.	W.	30
	2 a.m.	W.	29
	3 a.m.	W.	21
	4 a.m.	W.	18
	5 a.m.	S.W.	16
	6 a.m.	S.W.	18
	7 a.m.	W.	35
	8 a.m.	W.	35
	9 a.m.	W.	42
	10 a.m.	W.	56
	11 a.m.	W.	40
	12 a.m.	W.	38
	1 p.m.	W.	44
	2 p.m.	N.W.	44
	3 p.m.	W.	45
	4 p.m.	N.W.	36
	5 p.m.	W.	39
	6 p.m.	N.W.	37
	7 p.m.	N.W.	33
	8 p.m.	N.W.	37
	9 p.m.	N.W.	26
	10 p.m.	N.W.	25
	11 p.m.	N.W.	20
	12 p.m.	W.	18

notes were taken on a bulk sample from all replicates. A reasonably good differential was obtained in 1946 but the range was not so great in 1947. Threshed material from the experimental thresher may not be comparable to that from commercial machines, but it seems probable that such would be the case. Titan, Velvon, Glacier, Atlas, and Prospect were the most difficult varieties to thresh in these tests.

Pope (7) and Aberg and Wiebe (1) have shown that environment markedly influences the threshability of a variety. This is apparently brought about by its effect on the deposition of ash in the awn. Brittleness of awn has been shown to be closely associated with ash content by Harlan and Pope (5). Aberg *et al.* (2) have also shown a direct relationship between ash content and threshability.

TABLE 11.—MEAN PER CENT OF KERNELS THRESHING FREELY FROM BARLEY VARIETIES GROWN ON DRYLAND, 1946-1947

Variety	Per cent free threshing		
	1946	1947	Average
Atlas	63	78	70
Glacier	69	76	72
Prospect	61	83	72
Velvon	65	84	74
Titan	65	89	77
Plush	71	94	82
Trebi	75	95	85
Tregal	84	90	87
Vantage	87	92	90
Warrior	89	96	92
O.A.C. 21	92	94	93
Rex	91	97	94
Montcalm	94	95	94
Newal	98	94	96
Vance Smyrna	96	97	96
Compana	95	99	97

TABLE 12.—SUMMARY OF ANALYSIS OF COVARIANCE BETWEEN SHATTERING AND NECK BREAKING IN BARLEY VARIETIES

Year	F values			r_1	r_2
	Between varieties	Error before and after adjustment	Between regressions	Between varieties	Within varieties
Grown on dryland					
1943	8.35**	1.48	54.68**	0.930**	0.135
1944	4.35**	5.31*	3.43	0.560**	0.202*
1945	8.38**	0.32	66.02**	0.669**	0.036
1946	6.69**	1.27	44.17**	0.578**	−0.078
1947	21.19**	45.96*	91.00**	0.290	−0.457*
Grown on irrigated land					
1945	5.39**	0.61	12.07**	0.459**	−0.059
1946	2.14**	0.86	4.24**	0.376**	−0.080
1947	3.65**	0.14	0.76	0.111	−0.031

* Exceed the 5 per cent point.
** Exceed the 1 per cent point.

INTERRELATIONSHIPS

Shattering and Neck Breaking

A summary of the covariance analysis of the data on shattering and neck breaking is presented in Table 12. In five of the eight tests, namely the dryland tests in 1943, 1945 and 1946 and the irrigated tests in 1945 and 1946, there were highly significant positive relationships between these variables.

It is difficult to offer a satisfactory biological explanation for the positive and negative within variety associations between the variables that occurred in the dryland tests in 1944 and 1947. It is doubtful if the

r^1 values can be considered true estimates of the relationship between the variables in these two tests. Neither can an explanation be suggested for the lack of association between neck breaking and shattering in the 1947 test grown on irrigated land.

Neck Breaking and Stem Breaking

Data are available from the 1947 test on dryland only. An analysis of these data by covariance showed a between-variety correlation of 0.334 that just reached the point of significance, and a non-significant within variety correlation of 0.182. The data are not sufficiently extensive to draw definite conclusions, but they suggest that neck-breaking and stem-breaking tendencies are not closely associated.

Shattering and Threshability

The coefficients of correlation between percentage shattered and percentage free threshing in the 1946 and 1947 tests on dryland were 0.326 and 0.427, respectively. Both of these values exceed the 5 per cent point.

DISCUSSION

The results of this investigation have shown conclusively that varietal differences exist in the amount of damage from shattering and neck breaking that occurs under natural conditions. Furthermore, the magnitude of these differences is sufficiently great to be of considerable significance in evaluating varieties for commercial production. In the production of new varieties the desirability of incorporating resistance to shattering and breaking is evident. While fewer data are available on stem breaking and threshability, here again it would appear that important varietal differences exist and that resistance to stem breaking and ease of threshing are characters that should be incorporated into new hybrids.

The association between shattering and neck breaking will be of some assistance in a breeding program. Its degree of usefulness will probably depend upon the varieties used as parents. In any case the association is unlikely to be sufficiently close to warrant selection on the basis of one character only, except possibly in early-generation material.

On the other hand, the association between shattering and threshability is likely to prove troublesome. The data obtained suggest that the association is not close, but these data are meagre and may not indicate the true extent of the association. It seems probable that varieties can be produced which have resistance to shattering and which thresh satisfactorily, but such plants may be difficult to locate in segregating populations.

The pronounced effect of environment on all characters under discussion will need consideration in the breeding program. It may not be possible to secure a differential for all characters in any one test. The results suggest that differentials for neck breaking and threshability can best be secured under drought conditions while shattering is more pronounced when the crop is irrigated. The influence of different stations even within a natural region, such as the open plains area of Western Canada, has not been investigated but it seems probable that differences would exist. If this is so, then advanced hybrids, at least, should be tested at more than one station.

Undoubtedly improvements can be made in producing differential environments. By choosing locations fully exposed to prevailing winds both neck breaking and shattering would be increased, while the application of water by sprinklers when the crop is mature might increase shattering considerably. There is also the possibility of using mechanical tests and chemical determinations. Apparatus to test breaking strength and to produce shattering mechanically could probably be produced, while the possible relationships between shattering and threshability with ash content of the awns should be investigated. The greatest difficulty with all such tests is likely to be the time required to handle any large bulk of material. If they are developed they will likely be most useful for critical studies of factors affecting the characters involved and for detailed analyses of possible parental material. Field tests will probably remain the most efficient way of eliminating undesirable material from hybrid populations.

SUMMARY

Damage to barley varieties at and following maturity by wind and rain was studied. Shattering and neck breaking were noted in a series of varieties for five years when grown on dryland and for three years on irrigated land. Data on stem breaking were obtained in one test. Buckling was noted on certain varieties. In addition, the threshability of the varieties in two tests was recorded.

Highly significant varietal differences were established in all tests for all of the characters studied. These differences were large enough to be of economic significance. The variety Glacier was highly resistant to all types of damage, while the Manchurian types tended to be highly susceptible.

In most tests shattering and neck breaking were positively associated. Neck breaking and stem breaking, and shattering and threshability were also positively associated.

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DEVELOPMENT OF A FORMULA FOR ESTIMATING SURFACE RUN-OFF[1]

T. S. FORSAITH[2]

Dominion Experimental Station, Swift Current, Sask.

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INTRODUCTION

The anticipated rate and volume of surface run-off are essential factors in the design of any water control or storage structure that handles surface water.

A large number of small water conservation and irrigation projects have been built in the three prairie provinces, particularly since the inception of the Prairie Farm Rehabilitation Act in 1935. This type of work will continue in the future, and in addition there is a growing demand for run-off data in relation to water erosion control practices.

With regard to rate of run-off, the designer is primarily interested in the rate of flood flow that may be anticipated to be equalled or exceeded once, on an average, in a given period of years. The frequency period will depend on the importance and cost of the structure. Suggested values are: 10 years for small, readily replaced structures such as diversion ditches and terraces; 25 years for small earth dams; and 50 years for larger earth dams or where failure would cause serious inconvenience. Larger structures, where cost of replacement is high, or life endangered, will be designed for larger run-off rates.

Volume of surface run-off is regarded from a different viewpoint. Here the designer is not interested in the exceptionally high values, but in the dependable average. The frequency with which the usable water supply can be allowed to fall below a required minimum depends on the purpose of the water, cost of construction of reservoir, economic value of water, and hydrologic factors. Krimgold (9) defines a dependable water supply for the Claypan Prairies (Illinois, Indiana, Iowa, Missouri, Kansas, and Oklahoma) as being one which, on the average, can be depended upon 80, 90, or 96 per cent of the time. Data or information available to the engineer to assist him in estimating the probable rate or volume of surface run-off for a given watershed in the Southern Prairie region are not available in readily usable form. Design is often based on individual experience.

This article will discuss some of the aspects of the run-off problem for small watersheds, as commonly encountered in soil and water conservation work. An analysis of Dominion Water and Power Bureau records for streams of the Southern Prairies will be presented in an effort to bring existing data into a more usable and applicable form for the above purpose.

[1] Contribution from the Agricultural Engineering Research Laboratory, Dominion Experimental Station, Swift Current, Saskatchewan.
[2] Agricultural Engineer.

FACTORS INFLUENCING RUN-OFF

Precipitation falling on the land surface is disposed of as:

(1) Surface run-off to streams, lakes or ponds.
(2) Direct evaporation.
(3) Transpiration.
(4) Deep seepage beyond the range of plant roots. This water maintains the ground water supply, and may reappear as springs.
(5) Soil moisture accretion.

Surface run-off will occur when rain or melting snow is releasing water on the land surface faster than the earth can absorb it. The greater portion of the run-off volume, and most of the peak run-off rates, in this region, are the result of melting snow. Intense summer rains on occasion cause peak flood rates on watersheds of less than two square miles. These intense rains are usually local in extent, and hence affect a small watershed of a few acres much more than one of several square miles. Peak flood rates on large watersheds, due to extended, excessive summer rainfall, occur rarely in this region.

There are many factors that influence the rate and volume of run-off, and their inter-relation is so complex that, with the present meagre knowledge, it is impossible to evaluate them all in a simple expression. An expression giving run-off rate in terms of all the factors concerned would be attractive theoretically, but practically might have little value, and is not necessary.

Some of the factors affecting rate and volume of run-off will be briefly listed:

(1) *Watershed area.* The rate of run-off per unit area decreases with increasing watershed size. The volume of run-off per unit area may increase or decrease, depending on other watershed characteristics.
(2) *Climate.*
  (*a*) Type and frequency of excess precipitation.
  (*b*) Temperature. Areas where temperatures are below freezing for a portion of the year will have different run-off characteristics from areas where this is not the case. Temperature affects the rate of melting of snow and evaporation.
  (*c*) Wind and humidity, combined with temperature, affect the evaporation rate and hence the run-off.
  (*d*) Special local conditions, such as the chinook wind in South Alberta and Southwestern Saskatchewan.
(3) *Watershed shape.* A compact shaped drainage area will have a higher run-off rate than a long, narrow area of similar size.
(4) *Watershed exposure*, i.e., north or south facing.
(5) *Soil type.* The infiltration rate and capacity will influence the rate and volume of run-off.
(6) *Vegetative cover and land use.*
(7) *Average slope of the area.*
(8) *Topography and drainage pattern.*

The Southern Prairies are characterized by long, cold winters, and hot, often dry, summers. The total average precipitation is low, varying from a low of about 10 inches in Southeastern Alberta to a high of 16 to 20 inches in Southern Manitoba. Approximately one-quarter of this total may fall from November to March, largely as snow. June is normally the month of highest rainfall, with July and May following in order.

The spring thaw, occurring in the latter half of March or the first half of April, will normally produce some run-off, and the larger watercourses normally have their yearly peak run-off rate at this time. The smaller watercourses and coulees cease to flow as soon as the snow has gone, and only large rivers such as the Souris, or spring-fed streams as in the Cypress Hills continue to flow much after the end of June, except in years of abnormal precipitation.

The yearly peak rate and volume of run-off vary greatly from year to year, particularly on small watersheds. There are occasional zero values, and also the occasional very high run-off. Intense summer rains on occasion will cause a peak flow rate on small watersheds.

The run-off volume, or depth, is low, normal values ranging from a high of 3 inches for some streams of the Cypress Hills to less than 0.1 inch for the Souris River. The run-off volume varies greatly from year to year, and several consecutive years of subnormal run-off may occur quite frequently.

PRESENT STATUS OF THE PROBLEM

The Dominion Water and Power Bureau and its predecessors have maintained gauging stations, and secured run-off data for most of the larger rivers and streams in the Southern Prairies, starting in 1908. The records for individual streams vary greatly in length and completeness. The streams gauged are mainly those with larger drainage areas of from 15 to several thousand square miles, and the results therefore are not directly applicable to small drainage areas.

Many empirical formulae have been developed in the past for determining run-off rate. Most of these formulae were developed for a specific area, and great caution must be used in applying any such formula outside the conditions for which it was developed. The "Handbook of Applied Hydraulics" (3) lists 45 such formulae.

The United States Soil Conservation Service, and related agencies, have done much work in obtaining run-off data for small watersheds at various places within the United States. Krimgold (5, 6) deals at some length with the various factors and problems.

The "Rational Formula" has been used very considerably in the past in the United States for estimating the run-off rate from small agricultural areas. It takes the form: $Q = CIA$

where Q = peak run-off rate in c.f.s.
C = a run-off coefficient.
I = rainfall intensity in in./hr.
A = drainage area in acres.

Ramser (11, 12) was the first to apply this formula to agricultural areas, and to obtain values of the coefficient "C". The value of "I" depends on the location of the watershed, the estimated time of concentration and the frequency period. Values are selected from charts as in references (2, 10, 13). The value of the coefficient "C" depends on watershed slope, cover, soil texture, and many other factors, and is an estimate only.

Results of actual run-off measurement on small watersheds, and use of the above formula over a period of years, brought the realization that the many factors affecting run-off rate cannot be expressed satisfactorily in a single coefficient.

The method now coming into use is to derive run-off curves for different frequency periods from analysis of actual run-off data. A given curve will apply only to the area and conditions for which it was derived. As more run-off data become available, more and more of the country can be accurately covered. Krimgold (7, 8) expresses this trend of development. The method of presenting results from this method is well illustrated in reference (9).

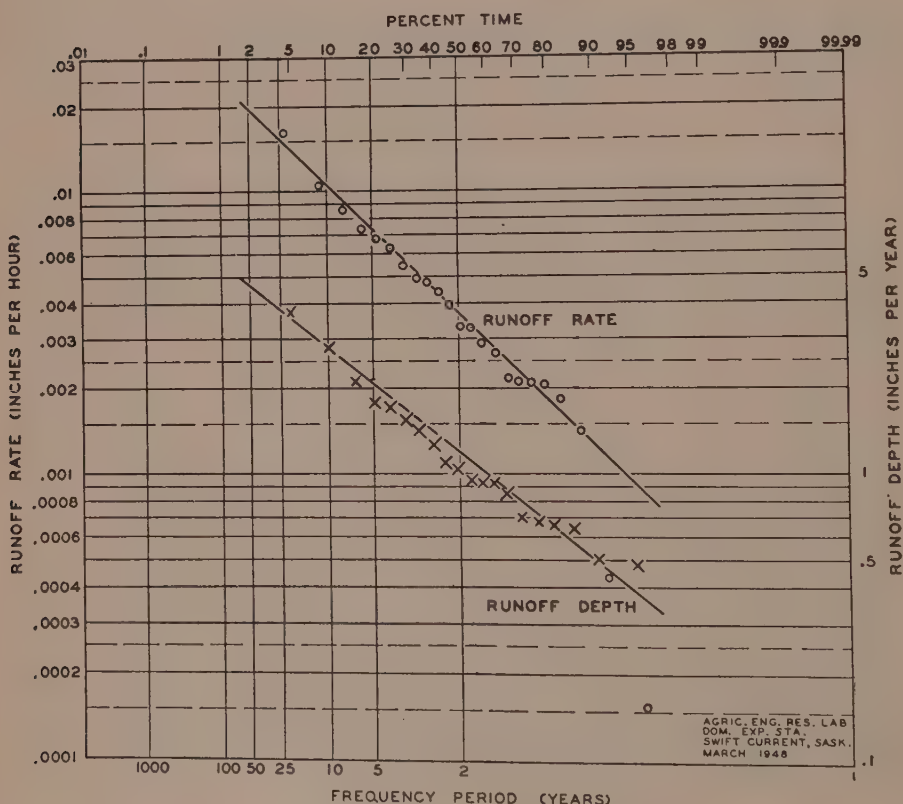

FIGURE 1. Run-off rate and depth frequency plotting for the Frenchman River at Eastend. (See Stream No. 23 in Table 1).

The Rational Formula has been discussed at some length due to its wide use in the United States. It applies to run-off from intense rain only, and does not apply to melting snow. There are few, if any, rainfall intensity records for Western Canada, so its use for the prairies is eliminated, except possibly in areas adjacent to the United States border where their data (13) might be applied.

The point which it is wished to emphasize is that, due to the limitations of the Rational Formula and the present lack of supporting data, no attempt should be made to apply it to the Prairie Region. Effort should be directed toward securing reliable run-off data to which probability analysis can be applied.

The Fuller Formula (4) has had some popularity. It was developed from records on United States rivers, largely those draining the more humid regions. The statement is made that streams having a "flashy" run-off characteristic, as in the more arid regions of the interior of the continent, do not fit the formula, and that the formula is not intended to be applied to those conditions.

The Meyer Formula (2, 3) has been developed from a study of all the principal streams and rivers in the United States.

The formula is of the form: $Q = qM = 100\ pM^{0.5}$

where Q = peak discharge, c.f.s.

q = peak discharge, c.f.s. per square mile.

M = drainage area, square mile.

p = the Meyer rating of the stream.

For areas under four square miles, it is suggested the formula change to: $Q = qM = 50\ pM$ or the run-off rate now varies as the first power of the area rather than the one-half power. Values of "p" are given for various streams on a map of the United States. The statement is made that the formula should be applied with caution for areas under 25 square miles. It will be noted that "Q" is the maximum, or limiting flood, and no mention is made of frequency.

The preceding has briefly discussed a few of the many run-off rate formulae.

ANALYSIS OF RUN-OFF RECORDS FOR STREAMS OF THE SOUTHERN PRAIRIES

The soil and water conservation studies, conducted at the Agricultural Engineering Research Laboratory, Swift Current, Saskatchewan, over the past ten years have revealed an acute need for more specific data on the rate and volume of run-off.

A beginning has been made on setting up run-off stations to measure the rate and volume of run-off from small agricultural areas in this region. However, some years must pass before sufficient data can be gathered to be of value. An attempt has been made to utilize existing stream flow data for use in the interval.

The run-off records of the Dominion Water and Power Bureau on streams of the Southern Prairies were analysed as described below. Only streams rising in this area were used; mountain streams and those with many lakes were excluded.

TABLE 1.—SUMMARY OF STREAM FLOW RECORDS FOR THE SOUTHERN PRAIRIE REGION

No.	Stream	Location of gauging station	Drainage area (sq. mi.)	Period of record	Run-off rate (in./hr.)—frequency in years**				Maximum discharge		Av. yearly run-off		Run-off vol.—Frequency**			
													2 year		1.25 year	
					2-year	10-year	25-year	50-year	In./hr.	Date	In.	Ac. ft./sq. mi.	Depth, in.	Ac. ft./sq. mi.	Depth, in.	Ac. ft./sq. mi.
1	Swift Current Creek	At Swift Current $5HD_7$	1160	1910–40	0.0013	0.0054	0.009	0.0127	0.00842	10 Apr. 17	0.92	49.0	0.82	43.8	0.48	25.6
2	Swift Current Creek	Sinclair's Ranch (Lower Sta.) $5HD_3$	366	1910–27 and 1936	0.0019	0.0042	0.0057	—	0.00394	Apr. 22	1.24	66.0	1.14	60.8	0.70	37.3
3	Swift Current Creek	Sinclair's Ranch (Upper Sta.)	172	1910–16	—	—	—	—	0.00227	8 Apr. 13	—	—	—	—	—	—
4	Swift Current Creek	Pollock's Ranch	16	1909–16	0.0015	0.0075	—	—	0.00543	17 June 16	1.17	62.2	1.12	59.8	0.64	34.1
5	Bone Creek	Lewis' Ranch	17	1910–16	—	—	—	—	0.0137	11 Apr. 12	—	—	—	—	—	—
6	Jones Coulee	Stearn's Ranch	23	1912–16	—	—	—	—	0.0027	20 June 15	—	—	—	—	—	—
7	Wood River	Near Gravelbourg $5JA_1$	2150	1918–25 and 1936	0.00074	0.0023	—	—	0.00655	30 Mar. 25	0.32	17.0	0.24	12.8	0.10	5.3
8	Notukeu Creek	Near Vanguard $5JB_1$	1421	1915–25, 1936 and 1940	0.0022	0.0045	—	—	0.0041	16 Apr. 40	0.42	22.4	0.33	17.6	0.15	8.0
9	Wiwa Creek	Near Gravelbourg	600	1921–25 and 1936	—	—	—	—	0.00413	29 Mar. 25	0.28	15.2	—	—	—	—
10	Moose Mountain Creek	At Oxbow, Sask. $5ND_2$	1900	1914–17, 1933–43	0.00026	0.0012	0.0021	0.003	0.00109	25 Mar. 39	0.13	6.9	0.09	4.8	0.031	1.7
11	Long Creek	Near Estevan	2240	1912–23,	0.00033	0.0012	0.0019	0.0026	0.00199	31 Mar. 43	0.137	7.3	0.115	6.1	0.030	1.6
12	Souris River	Glen Ewen, Sask.	6220	1912–17	—	—	—	—	0.00042	24 Apr. 16	—	—	—	—	—	—
13	Souris River	Melita, Man. $5NF_1$	19937	1912–22 and 1936	0.000098	0.00026	0.00037	—	0.000294	23 Apr. 16	0.108	5.7	0.1	5.3	0.052	2.8
14	Souris River	Estevan, Sask. $5NB_2$, $5NB_4$	4760	1911–23, 1923–43	0.00029	0.001	0.0014	0.0019	0.00156	6 Apr. 43	0.095	5.1	0.094	5.0	0.0054	0.29

15	Souris River	Wawanesa, Man. $5NG_1$	24150	1913–43	00.00097	0.00028	0.004	0.00052	0.000394	19 Apr. 16	0.071	3.8	0.031	1.7	0.0042	0.22
16	Oxarat Creek	Wylie's Ranch	77	1910–19	0.0018	0.015	—	—	0.0108	8 Apr. 12	0.84	44.8	0.68	36.3	0.31	16.5
17	Belanger Creek	Oake's Ranch $11AC_{16}$	65	1912–28, 1939–45	0.0076	0.021	0.0305	0.039	0.0297	22 Apr. 22	1.98	109.0	2.0	107.0	1.19	63.5
18	Sucker Creek	Gilchrist's Ranch $11AC_8$	30	1909–28 and 1939	0.0097	0.045	0.079	0.115	0.0501	4 Apr. 25	2.23	119.0	2.0	107.0	1.09	58.1
19	Davis Creek	Drury's Ranch $11AC_4$	45	1909–28	0.011	0.026	0.035	0.043	0.0337	25 Apr. 27	3.04	165.0	2.87	153.0	1.70	90.6
20	Fairwell Creek	Drury's Ranch $11AC_3$	125	1909–31	0.0065	0.014	0.018	0.022	0.0182	21 Apr. 17	2.22	119.0	2.1	112.0	1.32	70.4
21	North Branch of Frenchman River	At Cross' Ranch	53	1909–19	0.0037	0.0078	—	—	0.0069	6 Apr. 13	1.8	96.0	1.8	96.2	1.38	73.6
22	Frenchman River	At Belanger $11AC_{40}$	226	1917–28	0.0028	0.0078	—	—	0.0128	23 Apr. 23	0.92	49.6	0.74	39.4	0.32	17.1
23	Frenchman River	At Eastend $11AC_1$	648	1909–36	0.0037	0.0105	0.015	0.02	0.0167	Apr. 12	1.31	70.0	0.99	52.8	0.67	35.7
24	Frenchman River	At 50 Mile Crossing $11AC_{23}$	1130	1914–31, 1936–37	0.0019	0.0046	0.0063	0.0078	0.0045	23 Mar. 28	0.9	47.6	0.83	44.3	0.49	26.1
25	Frenchman River	At International Boundary. $11AC_{41}$	2020	1917–43	0.0011	0.0034	0.005	0.0065	0.00418	29 Mar. 25	0.67	36.0	0.58	30.9	0.30	15.9
26	Denniel Creek	Near Val Marie	182	1914–31, 1936–37	0.0025	0.0115	0.02	0.029	0.0203	18 June 23	0.55	29.4	0.42	22.3	0.19	10.1
27	Horse Creek	Near Barnard, Mont. $11AE_{0.3}$	71	1915–43	0.0043	0.015	0.023	0.032	0.0218	30 Mar. 25	0.92	49.0	0.68	36.3	0.31	16.5
28	McEacheran Creek	Near Theon, Mont. $11AE_{8.4}$	160	1915–43	0.0041	0.022	0.04	0.06	0.0391	9 Apr. 27	1.03	55.0	0.76	40.6	0.16	8.5

** To convert to per cent of time multiply 1/Frequency × 100.

TABLE 1.—SUMMARY OF STREAM FLOW RECORDS FOR THE SOUTHERN PRAIRIE REGION—*Continued*

No.	Stream	Location of gauging station	Drainage area (sq. mi.)	Period of record	Run-off rate (in./hr.)—frequency in years**				Maximum discharge		Av. yearly run-off		Run-off vol.—Frequency**			
													2 year		1.25 year	
					2-year	10-year	25-year	50-year	In./hr.	Date	In.	Ac.ft./sq. mi	Depth, in.	Ac. ft./sq. mi.	Depth in.	Ac. ft./sq. mi.
29	Rock Creek	Near Barnard, Mont. $11AE_{0.2}$	242	1915–43	0.0026	0.0086	0.013	0.018	0.0199	30 Mar. 25	0.86	46.0	0.70	37.3	0.30	16.0
30	Lodge Creek	Hart's Ranch	80	1911–15	—	—	—	—	0.0232	5 Apr. 12	—	—	—	—	—	—
31	Thelma Creek	English's Ranch	15	1912–22	0.0093	0.04	0.068	—	0.034	27 Mar. 18	3.64	194.0	2.0	107.0	0.90	48.0
32	Middle Creek	Ross' Ranch $11AB_1$	143	1909–31 and 1936	0.0026	0.012	0.02	0.029	0.0176	5 Apr. 12	0.88	47.0	0.54	28.8	0.21	11.2
33	Middle Creek	Hammond's Ranch $11AB_8$	299	1911–31	0.0018	0.0067	0.011	—	0.00604	24 Apr. 22	0.67	36.0	0.52	27.7	0.24	12.8
34	Lodge Creek	International Boundary	797	1910–43	0.0024	0.0073	0.011	0.014	0.0111	5 Apr. 12	0.66	—	0.56	29.8	0.31	16.5
35	McRae Coulee	International Boundary $11AB_{70}$	53	1927–43	0.0038	0.02	0.038	—	0.0286	29 Mar. 43	0.48	—	0.37	19.7	0.017	0.9
36	Ten Mile Creek	Tributary of Battle Creek	24	1911–15	—	—	—	—	0.0062	22 Mar. 15	—	—	—	—	—	—
37	Six Mile Coulee	Tributary of Battle Creek	42	1910–16	0.002	0.0063	—	—	0.00616	16 Feb. 16	1.36	74.0	1.2	64.0	0.67	35.7
38	Battle Creek	Battle Creek $11AB_3$	210	1910–32 and 1936	0.0042	0.0099	0.0135	0.0165	0.0139	27 Apr. 27	2.1	112.0	1.8	96.1	1.0	53.3
39	Battle Creek	Wilke's Ranch $11AB_{15}$	310	1913–26†	—	—	—	—	0.00532	9 May 17	—	—	—	—	—	—
40	Battle Creek	Above Cypress Lake West Inlet Canal $11AB_{76}$	240	1939–43	—	—	—	—	0.0093	23 Apr. 40	—	—	—	—	—	—
41	Battle Creek	Nash's Ranch $11AB_{10}$	500	1910–30 and 1936	0.0026	0.0071	0.01	0.0128	0.00938	9 Apr. 12	1.25	66.6	1.0	53.3	0.52	27.7

42	Battle Creek	International Boundary. $11AB_2$	726	1917-39*	0.0013	0.0056	0.0093	0.013	0.0068	Mar. 27	0.74	—	0.59	31.4	0.26	13.9
43	East Branch Battle Creek	International Boundary. $11AB_{0.3}$	98	1927–43	0.0033	0.0113	0.018	—	0.0113	21 Mar. 39	0.45	24.0	0.38	20.3	0.015	0.80
44	Lyons Coulee	International Boundary. $11AB_{0.2}$	47	1927–43	0.0065	0.022	0.035	—	0.0222	21 Apr. 40	0.8	42.7	0.64	34.2	0.06	3.2
45	Woodpile Coulee	International Boundary. $11AB_{0.1}$	70	1927–43	0.0052	0.027	0.049	—	0.0321	30 Mar. 43	0.71	37.9	0.62	33.1	0.055	2.9
46	Manyberries Creek	Near Manyberries $5AF_{10}$	137	1911–31, 1935–43	0.005	0.019	0.03	0.041	0.0239	20 Mar. 28	1.02	54.4	0.90	48.1	0.52	27.7
47	Irrigation Creek	Near Manyberries $5AF_8$	85	1916–30 and 1936	0.0017	0.006	0.0095	—	0.007	20 Mar. 28	0.32	17.2	0.25	13.3	0.036	1.9
48	Ketchum Creek	Near Manyberries $5AF_7$	74	1916-25 and 1936	0.0028	0.0098	0.0155	—	0.00915	25 Mar. 18	0.55	29.3	0.39	20.8	0.15	8.0
49	Canal Creek	Near Manyberries $5AF_9$	72	1917–25 and 1936	0.0024	0.0055	0.0074	—	0.0055	2 Apr. 17	0.48	25.7	0.39	20.8	0.19	10.1
50	Maynard Coulee	Near Onefour, Alta. $11AA_{24}$	12	1925–30	—	—	—	—	0.00452	23 May 27	—	8.5	—	—	—	—
51	Lindsay Coulee	Near Onefour, Alta. $11AA_{23}$	9	1925–30	—	—	—	—	0.0108	23 May 27	—	57.0	—	—	—	—
52	Raymond Coulee	$5AF_{24}$	28	1927–31 and 1936	—	—	—	—	0.0326	22 Mar. 28	—	—	—	—	—	—

* Diversion to and from Cypress Lake starting 1939.
** To convert to per cent of time multiply 1/Frequency × 100. † Record Incomplete.

TABLE 1.—SUMMARY OF STREAM FLOW RECORDS FOR THE SOUTHERN PRAIRIE REGION—*Concluded*

No.	Stream	Location of gauging station	Drainage area (sq. mi.)	Period of record	Run-off rate (in./hr.)—frequency in years**				Maximum discharge		Av. yearly run-off		Run-off vol.—Frequency**			
													2 year		1.25 year	
					2-year	10-year	25-year	50-year	In./hr.	Date	In.	Ac.ft./sq. mi.	Depth, in.	Ac. ft./sq. mi.	Depth, in.	Ac. ft./sq. mi.
53	Maple Creek	At Maple Creek	81	1909–19	0.0048	0.0094	0.012	—	0.0086	4 Apr. 12	1.28	68.0	1.18	53.0	0.66	35.2
54	Maple Creek	At Dixon's Ranch $5HA_{19}$	360	1916–30, 1933–39	0.0024	0.0068	0.0099	0.0127	0.0085	24 May 27	0.79	42.0	0.55	29.3	0.23	12.3
55	Gap Creek	At Small's Ranch	108	1909–16	0.0068	0.0142	—	—	0.0143	4 June 15	1.39	74.0	—	—	—	—
56	Gap Creek	Near Maple Creek	274	1911–15	—	—	—	—	0.0066	3 Apr. 15	—	51.0	—	—	0.78	41.6
57	McShane Creek	At Small's Ranch	28	1910–14	—	—	—	—	0.00393	8 Oct. 14	—	15.0	—	—	—	—
58	Bridge Creek	At Gull Lake $5HA_{15}$	213	1911–22	0.00044	0.0018	—	—	0.0016	13 Apr. 17	0.27	14.4	0.095	5.1	0.018	0.96
59	Bridge Creek	At Skull Creek P.O.	15	1910–14	—	—	—	—	0.00455	14 Mar. 14	—	—	—	—	—	—
60	Bridge Creek	At Raymond's Ranch	6	1911–16	—	—	—	—	0.0175	8 July 15	—	118.0	—	—	—	—
61	Skull Creek	Near Skull Creek P.O.	32	1909–14	—	—	—	—	0.0274	4 May 09	—	94.0	—	—	—	—
62	Skull Creek	At Doyle's Ranch $5HA_{16}$	20	1911–22	0.011	0.05	0.087	—	0.0622	20 Apr. 20	2.96	160.0	2.65	141.0	1.60	85.3
63	Bear Creek	Unsworth's Ranch $5HA_3$	97	1909–30 and 1936	0.0048	0.0114	0.0158	0.0192	0.0167	22 Apr. 22	1.9	101.0	1.7	90.7	1.03	54.9
64	Piapot Creek	Cumberland's Ranch	51	1909–19 and 1936	0.0021	0.012	0.023	—	0.0168	21 June 09	1.11	59.5	0.84	44.8	0.35	18.7
65	Hay Creek	Hay Creek School	22	1911–21	0.0024	0.0075	0.0115	—	0.00845	17 Mar. 18	1.08	58.0	0.85	45.3	0.35	18.7
66	Boxelder Creek	Young's Ranch near Walsh	104	1911–19	0.0019	0.0086	0.015	—	0.0067	9 Apr. 17	0.64	34.0	0.35	18.7	0.11	5.9
67	Mckay Creek	At Walsh	200	1911–19	0.0029	0.0125	0.0215	—	0.0112	11 June 16	0.95	51.0	0.64	34.1	0.215	11.4
68	East Branch, Mckay Creek	Grant's Ranch	77	1912–14	—	—	—	—	0.0228	3 Apr. 12	—	—	—	—	—	—

69	Ross Creek	At Irvine 5AH4	233	1911–30, 1935–44	0.0043	0.0024	0.0091	0.0108	0.0104	22 Apr. 22	0.88	47.0	0.72	38.3	0.28	14.3
70	Bullshead Creek	Burton's Ranch 5AH18	143	1910–31 and 1936	0.0028	0.0147	0.027	—	0.0243	10 July 24	0.9	48.0	0.77	41.1	0.38	20.1
71	Seven Persons Creek	At Medicine Hat 5AH8	544	1914–31 and 1935	0.00082	0.0027	0.0013	0.0057	0.0051	21 Mar. 18	0.33	17.0	0.24	12.3	0.025	1.3
72	Seven Persons Creek	At Seven Persons 5AH20	445	1921–30 and 1936	0.0008	0.0013	0.0077	—	0.00404	22 Mar. 28	0.43	16.0	0.18	9.6	0.054	2.8
73	Paradise Creek	Near Seven Persons 5AH22	112	1921–30 and 1936	0.0015	0.0115	0.021	—	0.0118	28 Mar. 28	0.41	22.0	0.26	14.0	0.083	4.4
74	Moose Jaw Creek*	McCarthy's Farm 5JF1	1900	1910–40	0.00016	0.0024	0.0018	—	0.0024	14 Apr. 27	0.26	13.8	0.14	7.8	0.034	1.8

** To convert to per cent of time multiply 1/Frequency × 100. * Dams on Moose Jaw Creek influence the run-off.

TABLE 2.—VALUE OF "k" IN THE EXPRESSION $r = \frac{k}{A^{0.5}}$

	Frequency		
	10-Year	25-Year	50-Year
Normal	0.14	0.21	0.285
Maximum	0.26	0.4	0.6
Minimum	0.035	0.06	0.13

The yearly run-off data, including yearly peak flow rate and date and yearly run-off depth, were tabulated separately for each stream. The peak run-off rates were reduced to inches per hour, and the volume to inches depth. These values were tabulated in descending order of magnitude. The percentage of time that each value was equalled or exceeded was calculated from the formula

$$p = \frac{100n}{y + 1} \quad \text{where} \quad \begin{aligned} p &= \text{per cent} \\ n &= \text{number of the occurrence} \\ y &= \text{number of years of record} \end{aligned}$$

The percentage was plotted against the corresponding value for run-off rate and volume respectively on logarithmic probability paper as in Figure 1. From the resultant curves, values of run-off rate for 2-, 10-, 25-, and 50-year frequencies and for run-off depth and volume, were tabulated for each stream in Table 1.

This method allows the frequency of a given peak flow rate to be determined. An estimate of the flood rate to be anticipated for a frequency period longer than the period of record may be made by extending the graph. Judgment must be used as the further the extension, the less reliable is the result.

There were 56 streams where the record was of sufficient length to warrant estimating the 10-year rate; 47 streams for the 25-year rate, and 26 streams for the 50-year rate.

For each of the 10-, 25-; and 50-year frequency periods, the run-off rate was plotted against the corresponding watershed area for each stream on log-log paper.

The resulting group of points did not fall on a single line, but as a group definitely indicated a relation between run-off rate and watershed area. A line with a slope of minus one-half fitted the points well (as in the Meyer formula), and this was the slope used.

The unit run-off rate for a given frequency period may be expressed:

$$r = \frac{k}{A^{0.5}} \quad \text{where} \quad \begin{aligned} r &= \text{run-off rate, inches per hour.} \\ A &= \text{watershed area, square mile.} \\ k &= \text{a coefficient.} \end{aligned}$$

or $Q = 646kA^{0.5}$ where Q = c.f.s.

The points scatter from the above line, but examination showed that the more extreme variations could be logically accounted for, if the watershed characteristics were considered.

Maximum and minimum lines to encompass all points, and a normal line, all on the minus one-half slope, were drawn for each frequency period.

From this, three values of "k", a maximum, minimum, and a normal were found for each frequency period.

The normal values of "k" in Table 2 may be expressed in terms of the Frequency Period, T: $k = 0.05T^{0.444}$

The peak run-off rate expectancy may now be expressed in terms of the Frequency Period (T) and the Watershed Area (A):

$$Q = 32.3A^{0.5}T^{0.444}$$

where Q = flood flow in c.f.s. that will be equalled or exceeded, on an average, once in a period of T years.
A = watershed area in square miles.
T = frequency period in years.

A coefficient must now be applied to compensate for variations from the normal due to watershed characteristics and other factors.

$$Q = C(32.3A^{0.5}T^{0.444})$$

where C = a coefficient depending on watershed location and characteristics.

or

$$Q = C(1.3a^{0.5}T^{0.444})$$

where a = watershed area in acres.

Values of the coefficient "C" to apply to specific locations and conditions were selected from an examination of the points representing individual streams on the Run-off Rate Watershed Area plottings.

The Run-off Chart, Figure 2, gives the run-off rate to be anticipated in a 10-year period for various values of the run-off coefficient. Conversion factors are given to convert values from the chart to 25- or 50-year frequency periods.

This chart applies to that area bounded by the United States-Canadian boundary, St. Mary, Oldman, South Saskatchewan, Qu'Appelle, and Souris Rivers.

In order to illustrate the application of Table 3 and Figure 2 to the solution of a practical problem in water conservation, the following example is given: A water storage reservoir is to be constructed on a watershed northeast of Hodgeville, Saskatchewan, in Township 14, Range 7, West of the Third Meridian. It is found that this watershed is tributary to Wiwa Creek. A survey of the drainage area indicates that its area is approximately seven square miles. The characteristics of the watershed indicate that a Run-off Coefficient of C = 1.0 (Table 3) may be used with reasonable safety.

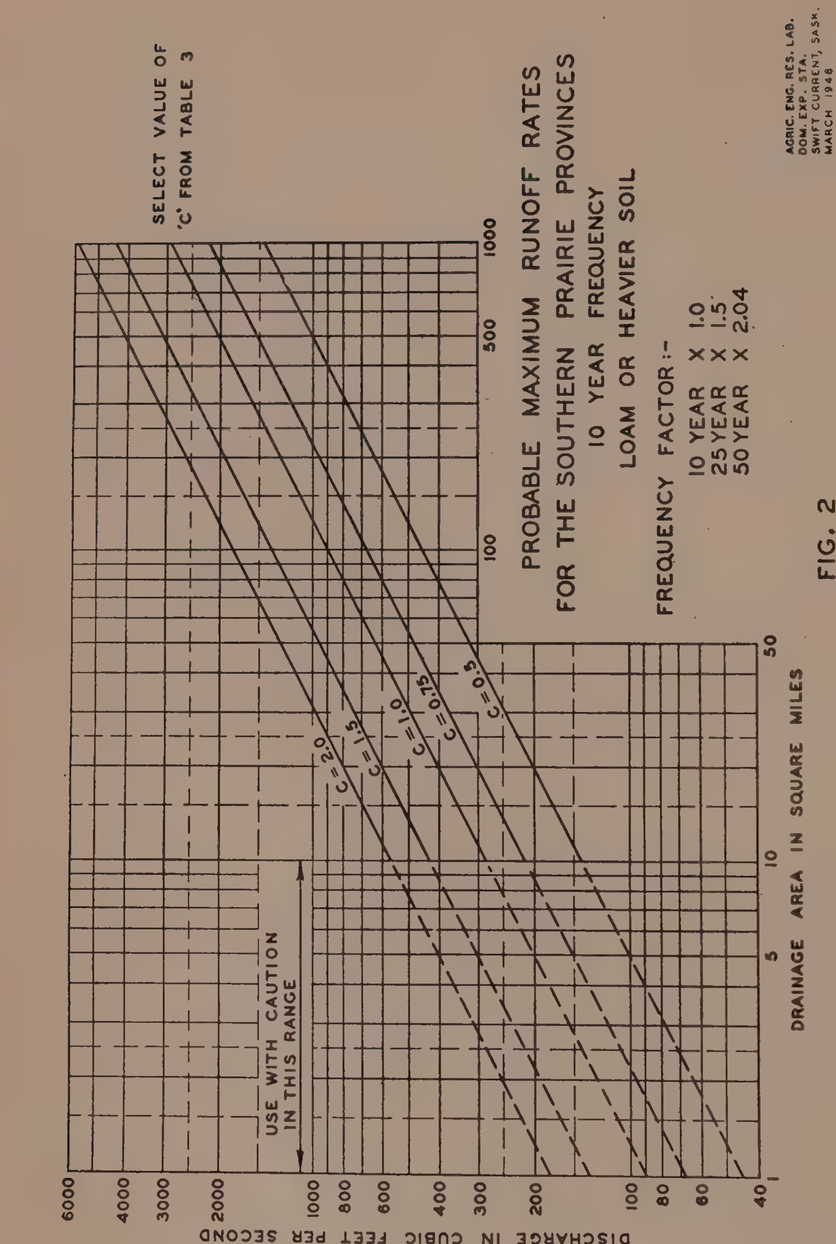
SELECT VALUE OF
'C' FROM TABLE 3
PROBABLE MAXIMUM RUNOFF RATES
FOR THE SOUTHERN PRAIRIE PROVINCES
10 YEAR FREQUENCY
LOAM OR HEAVIER SOIL
FREQUENCY FACTOR :-
10 YEAR X 1.0
25 YEAR X 1.5
50 YEAR X 2.04
AGRIC. ENG. RES. LAB.
DOM. EXP. STA.
SWIFT CURRENT, SASK.
MARCH 1948
USE WITH CAUTION
IN THIS RANGE
C = 2.0
C = 1.5
C = 1.0
C = 0.75
C = 0.5
DISCHARGE IN CUBIC FEET PER SECOND
6000
4000
3000
2000
1000
800
600
400
300
200
100
80
60
40
DRAINAGE AREA IN SQUARE MILES
1
5
10
50
100
500
1000

FIG. 2

TABLE 3.—VALUES OF RUN-OFF COEFFICIENT "C"

Value of "C"	Where applicable
2.0	The extreme rate. For steep, partially wooded watersheds in the higher elevations of the Cypress Hills, where conditions favour a very high run-off rate.
1.5	For fairly steep, hilly topography in the Chinook Area. Use for the area south of the Cypress Hills and Wood Mountain, and for the north slope of the Cypress Hills where conditions favour a high run-off rate.
1.0	The Normal Rate. This value could be used with reasonable safety where there are no factors indicating an exceptionally high or low rate.
	For level to moderately rolling topography south of the Cypress Hills and Wood Mountain area.
	For moderately steep to hilly topography north and east of Cypress Hills.
	For moderately to strongly rolling topography in Southeastern Saskatchewan and Southwestern Manitoba.
0.75	For level to gently rolling topography north and east of the Cypress Hills and Wood Mountain area.
	For moderately rolling topography in Southeastern Saskatchewan and Southwestern Manitoba.
0.50	The practical lower limit. For level to gently rolling topography, with only fair surface drainage, in Southeastern Saskatchewan and Southwestern Manitoba.

In order to determine the spillway requirements of the dam, it is necessary to know the maximum probable Run-off Rate. Enter Figure 2 at a drainage area of seven square miles. Proceed vertically to the diagonal $C = 1.0$. Thence proceed hortizontally to read the discharge rate of 240 c.f.s. This is the maximum probable discharge occurring once in ten years. A structure of this nature would probably be designed for a 25-year or 50-year frequency. The frequency factor for a 25-year maximum run-off is 1.5. Therefore, the spillway may be designed for a maximum discharge of $1.5 \times 240 = 360$ c.f.s., which will be equalled or exceeded once in every 25 years.

DISCUSSION

The following empirical formula has been proposed for the southern portion of the Prairie Provinces:

$$Q = C(32.3A^{0.5}T^{0.444})$$

Q is the peak flood in c.f.s. that may be anticipated to be equalled or exceeded, on an average, once in a period of T years.

C is the run-off coefficient, the value of which depends on the watershed characteristics and geographic location of the drainage area.

A is the watershed area in square miles.

T is the frequency period in years.

The designer must realize that a flood corresponding to a given frequency period may occur in any year, and that "T" years will not necessarily pass before the capacity of the structure is exceeded.

The above equation was derived from records of streams with drainage areas ranging from 15 to 24,000 square miles, and it is believed that reasonably reliable results may be obtained when the formula is applied within this range.

The length of record of the streams analysed does not warrant the use of a Frequency Period (T), greater than 50 years.

The gauging stations from which the records were obtained would be influenced, in some cases, by diversion or storage on the watershed above the station. This will tend to decrease the run-off rate and, therefore, the results presented here must be regarded as being somewhat low. On the other hand, the run-off depth values given may be regarded as conservative, and the actual run-off will be higher.

This range of application covers a large number of small water conservation projects, highway bridges and culverts, and the like.

There are many cases where the drainage area involved is less than 15 square miles. The above equation probably can be applied with fair results to drainage areas of five square miles or greater; however, no claim is made for the accuracy of the results until checked by actual experience.

The author does not know whether or not the formula is applicable to drainage areas of less than five square miles, and this must await checking by actual measurement. The Meyer Formula (2, 3) suggests that the relation change to a function of the first power of the area for watersheds under four square miles. This was tried but the results appeared low. The suggestion is that, if this formula be applied to small areas under five square miles, it be left in the form given for the larger areas. The result should be conservative.

The values for run-off depth in Table 1 may be used for estimating the volume of run-off from a given area by using the value from the table for a similar stream in the same area.

Run-off volume tends to decrease with increasing size of drainage area; hence for small areas, values in Table 1 are probably conservative.

The normal run-off depth values for the Souris River are very low, about 0.1 inch. The Souris is a large river, and the watershed area contains a considerable portion of indefinitely drained land. It is suggested that for small, fairly well drained areas in Southeastern Saskatchewan and Southwestern Manitoba run-off depths of three to four times the values for the Souris River might safely be used.

Run-off volume varies considerably for watersheds in the same general area. The values in Table 1 represent the run-off from fairly well drained watersheds with a loam or heavier soil. There are many areas of light textured soils where the normal run-off depth will range down to zero.

The normal, or two-year frequency, depth of run-off is always lower in value than the average. This is due to years of exceptionally high run-off unduly affecting the average. The normal value is the better for general use.

The run-off depth for the 1.25 year frequency, in Table 1, represents the depth that will be equalled or exceeded once, on an average, each 1.25 years, or 80 per cent of the time.

It is hoped that this paper may serve to consolidate existing data on run-off for the Southern Prairies, and prove helpful to those engaged in small soil and water conservation projects.

No doubt, there is much room for improvement in the estimation of run-off rates from small areas, but little can be done until data from small drainage areas are available.

One run-off measuring station, to record the run-off from a 140-acre watershed, was set up in 1947 at the Dominion Experimental Station, Swift Current, Saskatchewan. It is hoped that in the future more such stations may be set up throughout this region to secure records on the run-off from small areas.

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THE PROBLEM OF UNDERSIZE FRUIT IN KIEFFER PEAR ORCHARDS[1]

G. S. RANDHAWA[2], W. H. UPSHALL[3], AND H. B. TUKEY[4]

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During the past twenty years the Kieffer pear (P. *pyrifolia* × P. *communis*) has assumed considerable importance in Ontario, where it is used mainly for commercial canning purposes. In most of the Kieffer orchards a proportion of the trees show premature autumnal leaf-colouration (September and October) and bear undersized fruits of poor quality. Observations in Ontario nurseries show that from 3 to 10 per cent of the Kieffer trees exhibit a similar early autumn leaf-colouration. The trees which have shown early autumn leaf-colouration in nursery and orchard are usually dwarfish and show higher than normal mortality in the orchard. At times the fruit is so small that its sale is almost impossible.

These abnormal trees appear to occur at random throughout an orchard. Where an entire orchard, or one or more portions of it, is bearing small fruit, the trouble is probably due to poor physical condition of the soil or to unfavourable nutrient level.

The observations and experiments in this paper are presented to show the factors involved in the problem and to suggest some means of avoidance and correction.

EXPERIMENTAL MATERIAL AND METHODS

Physical Measurements

Tree-size—The cross-sectional area of the trunk, computed from girth measurements, was used as an index of tree-size.

Fruit-size—Fruit size was determined by weighing a number of fruits and recording the average.

Swelling at the graft-union—The diameter of the stock and scion was recorded at a distance of 2 cm. both above and below the union. The diameter at the point of union was also recorded. The difference between the average of stock and scion diameters and the diameter at the union was used as a measure of the swelling at the union.

Obstruction to passage of water and carbohydrates at the union—The methods reported by Chang (6) were used. The suction applied was equivalent to 700 mm. of mercury.

Strength at union—The apparatus used to determine the strength of the graft-union is shown in Figure 1. In this figure, A was a fixed point, the distance from point A to point B was 4 inches, and the distance from point B to point C was 40 inches. Thus there was a tenfold leverage. V was the vise which held the graft-union firmly in place. Pressure was applied at point C. A pressure of one pound with the fruit pressure-tester gave a force of 10 pounds at the graft-union. This force was expressed in pounds required to break one sq. cm. of cross-sectional area at the graft-union.

[1] The laboratory work was done by the senior author in partial fulfilment of the requirements for the degree of Doctor of Philosophy at Michigan State College.
[2] Research Scholar, Government of India.
[3] Chief in Research, Horticultural Experiment Station, Vineland Station, Ont.
[4] Head, Department of Horticulture, Michigan State College, East Lansing, Mich.

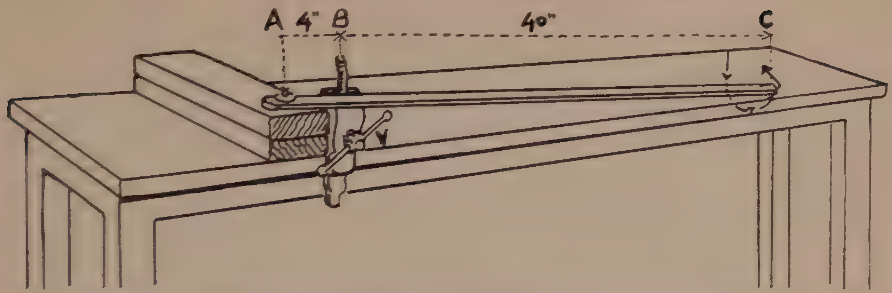

FIGURE 1. Diagram of breaking apparatus used for measuring the strength of the graft-unions.

Chemical Measurements

Total acidity—The acidity of the fruit was determined from a mixture of 100 gm. of fruit and 100 ml. of water thoroughly macerated in a Waring Blendor. A 10-ml. sample was titrated with N/10 sodium hydroxide using phenolphthalein as indicator. The volume of sodium hydroxide required to neutralize this quantity was used as an index of acidity.

Total solids—The refractometer was used to measure the total solids in the pear juice.

Ascorbic acid—Ascorbic-acid content was measured by the method advocated by Lucas (8).

Tissue analysis—The material was air dried and ground. It was analysed for nitrogen, potassium, calcium, phosphorus, and total ash by Official Methods (3). Calculations were on the dry-weight basis.

Soil analysis—Spurway's methods were employed for determining the nutritional status of the soil (11).

RESULTS

Orchard Trees

Relationship between Leaf Colouration, Size of Tree, Size and Quality of Fruit

Green leaves were always associated with large trees and with large fruits of good quality, whereas red leaves were always associated with small trees and with small fruits of poor quality (Table 1). In comparison to the red-leaved trees, the green-leaved ones bore fruits with a significantly higher content of ascorbic acid. Total acidity, however, appeared to have no relationship to the colour of the foliage. Fruits from red-leaved trees were more gritty, i.e., contained more stone cells, were more astringent, and had a thicker hypodermal layer than fruits from green-leaved trees.

TABLE 1.—RELATIONSHIP BETWEEN AUTUMNAL LEAF COLOURATION, SIZE OF TREE, SIZE AND QUALITY OF FRUIT, VINELAND ORCHARDS, OCTOBER, 1948

Determination	Green-leaved trees, average of 4 trees*	Red-leaved trees, average of 4 trees*
Area of trunk x-section (sq. cm.)	200.1	105.2
Weight per fruit (gm.)	112.4	63.5
Total solids (%)	7.8	6.3
Total acid index	3.9	3.8
Ascorbic acid (mgm. per 100 gm.)	6.7	4.4

* For orchard and position see Table 2.

Chemical Analysis of Leaves

In both Ontario orchards the nitrogen and calcium contents were appreciably higher in green leaves than in red ones (Table 2). In the Troup orchard, the green leaves also contained more potassium, phosphorus and total ash than the red leaves. However, in the Culp orchard, this was not the case.

TABLE 2.—CHEMICAL ANALYSIS OF PEAR LEAVES, VINELAND ORCHARDS, OCTOBER, 1948*

Tree	Foliage colour	N	K	P	Ca	Total ash
		%	%	%	%	%
Troup orchard						
Row 1, Tree 19	Green	1.52	1.01	0.11	1.49	5.48
Row 1, Tree 18	Red	1.31	0.66	0.09	1.33	4.35
Row 2, Tree 14	Green	1.50	0.56	0.12	1.53	5.01
Row 2, Tree 13	Red	1.15	0.20	0.08	1.39	4.64
Row 5, Tree 17	Green	1.64	0.87	0.10	1.67	6.39
Row 5, Tree 16	Red	1.33	0.81	0.09	1.35	5.50
Culp orchard						
Row 3, Tree 17	Green	1.73	0.88	0.09	2.19	5.18
Row 3, Tree 16	Red	1.43	1.07	0.11	1.50	6.71

* Red- and green-leaved trees were paired, each individual tree representing an approximate average for its class in each orchard.

Soil Analysis

The soil beneath the trees listed in Table 2 was analysed for active and reserve nitrogen, phosphorus, potassium, and calcium, and for acidity (pH). There was no significant difference in the nutrition status of the soils upon which the two types of trees stood. Apparently premature autumn leaf-colouration was not associated with the lack of soil fertility in the cases under study.

Nursery Trees

Behaviour of Red-leaved Nursery Trees After Planting in the Orchard

The standard Kieffer trees with green foliage are usually larger in size in the nursery row than those with red foliage. Measurements of trunk cross-section, taken in 1948, of one-year trees on domestic seedlings gave the following averages: green leaf (70 trees), 1.86 sq. cm.; red leaf (8 trees), 1.38 sq. cm. This difference often widens year by year when these trees are transplanted to the orchard (Table 3). The size difference in the nursery may not seem to be very striking but the presence of these dwarf trees in the orchard may have an appreciable bearing on the total yield. There is a suggestion, however, that not all of the trees which show red leaves in the nursery develop into dwarf trees in the orchard; two of the six for which data are given in Table 3 are not dwarf trees. That these were the largest of the red-leaved trees in each lot at planting time is worthy of note. Some of the trees, originally red-leaved in the nursery, are now very dwarf trees but seldom show early leaf colouration or small fruit-size. In other words, uncongeniality with the rootstock is now being demonstrated in a different way. In a standard commercial orchard, however, these abnormal trees are still quite undesirable.

TABLE 3.—TRUNK CROSS-SECTIONAL AREA AND FOLIAGE-COLOUR RELATIONSHIPS OF 11 KIEFFER PEAR TREES IN NURSERY AND ORCHARD

Time of planting in orchard	Rootstock	Trunk cross-sectional areas (sq. cm.)			
		Green leaves		Red leaves	
		At planting	1948	At planting	1948
Fall, 1939	Fr. pear	2.5	28.7	1.3	8.1
		2.0	37.8	1.8	12.2
		2.5	47.4	2.3	45.8
Fall, 1943	Kieffer seedlings	1.3	38.9	0.8	18.6
		5.3	24.4	1.3	39.2
		—	—	0.8	23.5

Chemical Analysis of Tops (including leaves)

The woody tops and leaves of the green-leaved Kieffer trees had an appreciably higher content of nitrogen and calcium than those of the red-leaved trees (Table 4). This is the same relationship as found in orchard trees. Regarding potassium, the woody tops of the red-leaved trees had a higher content than the green-leaved trees but no such trend was found in the leaves. The woody tops of the green-leaved trees had less ash and phosphorus than the tops of the red-leaved trees but the green leaves contained more phosphorus and ash than the red ones. The leaves had a much higher percentage of total ash than the tops in both types of tree.

TABLE 4.—CHEMICAL ANALYSIS OF WOODY TOPS AND LEAVES OF KIEFFER PEAR TREES IN THE NURSERY ROW

Number of of trees analysed	Foliage colour in October	Portion of tree	N	K	P	Ca	Total ash
			%	%	%	%	%
Lot 1							
2	Green	Tops	1.52	0.72	0.08	0.37	2.04
		Leaves	1.64	1.85	0.15	1.48	7.47
2	Red	Tops	1.15	0.79	0.11	0.33	3.03
		Leaves	1.31	1.35	0.10	0.70	4.80
Lot 2							
2	Green	Tops	1.50	0.47	0.08	0.52	2.17
		Leaves	1.73	1.05	0.14	1.55	7.13
2	Red	Tops	1.33	0.80	0.11	0.37	3.05
		Leaves	1.43	1.39	0.12	0.76	5.24

Swelling at the Graft-union

The Kieffer trees with red foliage had greater swelling at the union than those with normal green foliage (Table 5). In red-leaved trees the graft-unions were rough in outer appearance while in green-leaved trees they were smooth and symmetrical. Bradford and Sitton (5) and Amos *et al.* (1) found that there was no direct correlation between degree of swelling at the union and congeniality. Other writers on stock-scion

compatibility, however, report an association between swelling at the union and lack of congeniality (2). Proebsting (10) noted interference with translocation across certain graft-unions and found a relation to swelling at the union. In the present studies a similar relationship was found.

TABLE 5.—MEASUREMENT OF SWELLING AT THE GRAFT-UNION BETWEEN KIEFFER AND DOMESTIC PEAR SEEDLINGS

Combination	Number of trees	Age of top	Average diameter of trunk 2 cm. above and below union (A)	Diameter of union (B)	Swelling at union (B minus A)
			cm.	cm.	cm.
Lot 1—Fall, 1946					
Kieffer (green leaf)	3	2 years	1.30	1.72	0.42
Kieffer (red leaf)	3	2 years	1.46	2.13	0.67
Lot 2—Fall, 1947					
Kieffer (green leaf)	4	2 years	1.81	2.26	0.45
Kieffer (red leaf)	4	2 years	1.61	2.18	0.57
Lot 3—Fall, 1947					
Kieffer (green leaf)	1	1 year	1.08	1.70	0.62
Kieffer (red leaf)	1	1 year	1.19	1.95	0.76

Obstruction to the Passage of Water in the Region of the Union

Less water passed through the red-leaved Kieffer graft-unions than through the green-leaved graft-unions (Table 6). Evidently, there is more resistance to the passage of water at the point of union in the red-leaved trees.

TABLE 6.—WATER CONDUCTIVITY THROUGH THE GRAFT-UNION

Combinations	Number of trees	Age of top	Mean cross-sectional area	Mean total water passed in one hour	Water passed per hour per sq. cm. cross-section
			sq. cm.	cc.	cc.
Lot 1—Fall, 1946					
Kieffer (green leaf)	3	2 years	1.33	56.5	42.5
Kieffer (red leaf)	3	2 years	1.69	35.9	21.5
Lot 2—Fall, 1947					
Kieffer (green leaf)	4	2 years	2.57	125.1	48.7
Kieffer (red leaf)	4	2 years	2.03	79.8	39.3
Lot 3—Fall, 1947					
Kieffer (green leaf)	1	1 year	0.95	35.2	37.0
Kieffer (red leaf)	1	1 year	1.00	28.7	28.7

Starch Accumulation at the Union

Red-leaved Kieffer trees (nursery) showed a deposit of starch above the union while green-leaved trees showed no such deposit. This indicates that the translocation of elaborated foods from the scion to the stock was not normal in the red-leaved trees. As a result, there was an accumulation of the products of photosynthesis (mostly carbohydrates) above the union. This condition is known to favour anthocyanin formation (9). The partial check to the passage of elaborated foods from scion to stock "starves" the stock which in turn dwarfs the scion.

Strength at Union and Nature of Fracture at the Graft-union

The graft-union of nursery trees having red foliage was weaker than that of trees with green foliage. The nature of the fracture at the union was moderate in the former case, and tearing in the latter (Table 7). The results with the red-leaved trees in this test were similar to those reported by Chang (6) for incompatible combinations.

TABLE 7.—STRENGTH AT UNION AND NATURE OF FRACTURE AT THE GRAFT-UNION

	Two-year Kieffer on domestic pear seedlings				
	Number of unions	Diameter at union	Total pressure required to break	Pressure to break per sq. cm. x-sec. area	Nature of fracture
		cm.	lb.	lb.	
Kieffer (green leaf)	3	1.72	163.0	70.8	Tearing
Kieffer (red leaf)	3	2.13	137.0	36.5	Moderate

DISCUSSION

These studies indicate that with the Kieffer pear the relationship between premature autumnal leaf colouration and small size of fruit is due to nutritional difficulties brought about by a poor graft-union.

The graft-unions of red-leaved Kieffer trees show a partial check to the passage of water and elaborated foods at the point of union. In contrast to the graft-unions of green-leaved trees, they are weaker and show greater swelling. In a congenial graft, water, mineral nutrients, and elaborated foods are freely exchanged between stock and scion. However, in uncongenial grafts there is a partial check to the passage of these materials in the regions of the union, which adversely affects the growth, cropping and longevity of the trees.

Experiments at Vineland Station show that these "off-type" pears are not due to differences in strain (7). Poor soil may result in early leaf colouration and undersize fruits but in the present investigations the soil-analysis figures did not furnish an explanation of the differences in behaviour found in the abnormal trees.

The deficiency of nitrogen and calcium encouraged anthocyanin formation in the leaves. Blank (4) reports that a decrease in nitrogen increases anthocyanin formation in barley kernels. Meyer and Anderson (9) agree that a deficiency of nitrogen favours anthocyanin formation. Results of the present investigations are in accord with the observations of these authors. Calcium had a close relation to nitrogen in the Kieffer leaves. As with nitrogen, a deficiency of calcium seems to encourage anthocyanin formation. Blank (4) says that Lundegardh found calcium deficiency in the tomato to be the cause of an increase in formation of anthocyanin pigment.

Two conditions tend to cause an accumulation of carbohydrates in the tops of the abnormal trees: (1) obstruction to the downward flow of carbohydrates at the union, and (2) resistance to the upward flow of nitrogen at the union, which limits the synthesis of amino acids from the carbohydrates. On the other hand, the early colouration of the foliage undoubtedly reduces the total carbohydrate supply in the tree through a reduction in photosynthesis.

Orchard experience suggests that Kieffer (P. *pyrifolia* × P. *communis*) is not always congenial on French or domestic pear (P. *communis*) seedling rootstocks, nor does it always do well on its own seedlings (Table 3). A better rootstock for Kieffer would be desirable. Unless such a rootstock becomes available it may be wise to grow Kieffer on its own roots. Tukey (12) records the existence of such an orchard in the Hudson Valley, New York. The trees in this orchard are very healthy, productive and uniform. The chief possibility of getting Kieffer on its own roots is from cuttings. Considering the popularity of Kieffer pears with the canners, the growers should think seriously about using own-rooted Kieffer trees for future plantings. Unfortunately propagation of Kieffer from cuttings is not a commercial possibility in Ontario or in the north-eastern part of United States. Growers will probably have to get own-rooted Kieffer trees from Georgia or adjoining states where Kieffer can be propagated from cuttings.

At present the best plan appears to be the elimination of all small red-leaved Kieffer trees from the nursery. Because of the high fertility conditions common to nurseries, it is possible that some trees with poor unions will show little evidence of stress in the nursery, but in the orchard, under less favourable conditions, will show various signs of uncongeniality. Such trees should be replaced early in the life of the orchard.

CONCLUSIONS

Premature autumnal colouration of the leaves of the Kieffer pear, small size and poor quality of fruit, may be due to nutritional difficulties brought about by a poor graft-union. A low level of nitrogen and calcium seems to favour anthocyanin formation in Kieffer leaves.

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CONGENIALITY OF SOME PEAR VARIETIES ON QUINCE A[1]

G. S. RANDHAWA[2] AND W. H. UPSHALL[3]

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Quince A (Angers) is the most common dwarfing rootstock for pears. Unfortunately there is frequent disagreement between scion and rootstock, varying in degree and nature with each variety. Bosc gives a poor take of buds and poor growth in the nursery but recovers its vigour in the orchard. Kieffer takes and grows well in the nursery but survives only a year or two in the orchard. The unions of Bartlett, Clapp Favorite, and Kieffer are weak, subject to breakage by wind in the nursery, or by handling at time of digging. On the other hand, Anjou, Duchess, Hardy, and Old Home seldom show signs of incompatibility, and the unions seem reasonably strong. These varieties are now being tested at Vineland as intermediate stocks for Bartlett and Bosc.

REVIEW OF LITERATURE

Argles (1) has given a very complete summary of investigations on this subject. His Table 1 (Appendix) gives the results with many varieties on quince stocks in various parts of the world and shows some instances of variability in behaviour from one country to another.

METHODS AND MATERIALS

The methods used in this investigation were the same as already reported in another paper (3) and were based on extensive experimental work on incompatibility by Chang (2). Part of the nursery trees used were grown at the Ontario Horticultural Experiment Station, and part in Ontario nurseries. All were No. 1 trees representative of the particular combinations and ages.

TABLE 1.—PERCENTAGE INCREASE IN DIAMETER AT THE UNION COMPARED TO THE AVERAGE 2 CM. ABOVE AND BELOW IT*

Age of top	Scion variety	Quince A rootstocks	Domestic pear seedling rootstocks
One-year	Bartlett	57	32
	Clapp Favorite	53	21
	Old Home	48	
	Hardy	36	
	Orange quince	25	
Two-year	Kieffer	60	
	Anjou	33	
	Old Home	31	
	Hardy	30	

* Six trees of each combination.

[1] Adapted from a thesis submitted by the senior author in partial fulfilment of the requirements for the Degree of Master of Science in Agriculture at the Ontario Agricultural College.
[2] Research Scholar, Government of India.
[3] Chief in Research, Horticultural Experiment Station, Vineland Station, Ont.

RESULTS

Swelling at Union

Pear on quince results in an appreciable swelling at the union compared with pear on domestic pear seedlings and with Orange quince on Quince A (Table 1). The varieties considered least congenial with the quince, viz., Kieffer, Bartlett, and Clapp Favorite show greater swelling at the union than the more congenial varieties, Old Home, Hardy, and Anjou.

Rate of Vacuum-induced Water Flow Through the Union

For this test, the trees were freshly cut off 4 cm. above the union and the same distance below it. Through this 8-cm. section water was drawn by a force equivalent to 700 mm. of mercury. Measurements of water flow were commenced 10 minutes after the apparatus was connected and readings were taken every hour for four hours. Results were expressed on the basis of 1 sq. cm. of cross-section, using the average of diameters 2 cm. above and below the union (Table 2).

It is clear that the unions between Bartlett, Clapp Favorite, and Kieffer as scions and Quince A as rootstock offer considerable resistance to an "artificial" flow of water in the laboratory. The reason for the slow flow of water through the Orange quince union with Quince A is not clear though there is a possibility that the Orange quince scion wood offers high resistance. There was less resistance to water flow through the unions of Old Home and Hardy on Quince A than through the unions of Bartlett and Clapp Favorite on domestic pear seedlings.

TABLE 2.—RATE OF VACUUM-INDUCED WATER FLOW THROUGH THE UNION*

Age of top	Scion variety	Quince A rootstocks	Domestic pear seedling rootstocks
		cc. per hour per sq. cm.	
One-year	Bartlett	17.2	42.8
	Clapp Favorite	10.5	41.8
	Old Home	55.9	
	Hardy	61.1	
	Orange quince	20.8	
Two-year	Kieffer	13.1	
	Anjou	40.7	
	Old Home	44.7	
	Hardy	54.7	

* Six trees of each combination.

Starch Accumulations at the Union

Iodine tests on longitudinal sections through the unions of dormant trees showed heavy deposits of starch above the unions of Bartlett, Clapp Favorite, and Kieffer on Quince A but no such accumulation in Bartlett and Clapp Favorite on domestic pear seedlings, or in Old Home, Hardy, or Anjou on Quince A. There was some accumulation of starch *below* the unions of Orange quince on Quince A.

Bark and Wood Continuity at the Union

Kieffer on Quince A showed discontinuity in both wood and bark. Sometimes Bartlett and Clapp Favorite were in this class also, but more often the bark was continuous and wood discontinuous. All of these combinations showed a more or less prominent brown layer at the union. In Bartlett and Clapp Favorite on domestic pear seedlings, and in Old Home, Hardy, and Anjou on Quince A, both bark and wood were continuous and there was no brown line at the union.

Strength at Union and Nature of Fracture

It took over three times as much force to break the unions of Bartlett and Clapp Favorite on domestic pear seedlings as was required to break the relatively weak unions that these varieties made with Quince A (Table 3). On the other hand, Old Home, Hardy, and Anjou made such strong unions with Quince A that breakage occurred first on the stem of the rootstock just below the union.

TABLE 3.—STRENGTH AT UNION (LB. PER SQ. CM.) AND NATURE OF FRACTURE*

Age of top	Scion variety	Quince A rootstocks	Domestic pear seedling rootstocks	Nature of fracture
One-year	Bartlett	27	—	Smooth
	Bartlett	—	83	Tearing
	Clapp Favorite	25	—	Smooth
	Clapp Favorite	—	84	Tearing
	Old Home	broken below, not at union		
	Hardy	broken below, not at union		
	Orange quince	90	—	
Two-year	Kieffer	26	—	Smooth
	Anjou	broken below, not at union		
	Old Home	broken below, not at union		
	Hardy	broken below, not at union		

* Four trees of each combination.

DISCUSSION

All of the tests discussed in this paper show that Bartlett and Clapp Favorite are not congenial with the Quince A rootstock. This does not necessarily mean, however, that the trees will be short-lived. Given adequate continuous support in orchard or garden they may live for many years, but without support, intentional or otherwise, they are likely to break at the union when subjected to strong winds. Experience in Ontario has shown that Kieffer on Quince A will not survive for more than a few years in the orchard even when given adequate support. On the other hand, Old Home, Hardy, and Anjou appear to make strong unions with Quince A, so strong that one might be tempted to say supports are not required. However, lacking the assurance of tests under orchard conditions, it is probably desirable to give support also to these latter varieties. A union good in the nursery does not necessarily assure a continuously good union in the orchard.

SUMMARY

Bartlett, Clapp Favorite, and Kieffer are not congenial with Quince A rootstocks, their uncongeniality being demonstrated in the nursery by abnormal swelling at the union; by resistance to flow of water through the union; by starch accumulations above the union; by discontinuity of bark or wood tissues at the point of union; and by ease of breakage at the union. Old Home, Hardy, and Anjou seem to be reasonably congenial with the Quince A rootstock.

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SEEDLING AND CLONAL ROOTSTOCKS FOR PEARS

W. H. UPSHALL[1] AND G. H. DICKSON[2]

Horticultural Experiment Station, Vineland Station, Ontario

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In pear orchards, Kieffer particularly, there is often considerable variation in the time that the leaves of individual trees begin to take on the bright red and purple autumn colours. The same situation prevails in the nursery row where it is quite common to see, even as early as August, a small proportion of the trees beginning to show these high colours. By October, the colours of these same trees are very pronounced and defoliation may have commenced. These off-colour trees occur in blocks budded on French pear, American domestic pear, and Kieffer seedlings. Where the affected trees are concentrated in one or more areas of the orchard or nursery, unfavourable soil conditions are probably responsible but, where they are scattered throughout the whole planting, rootstock or graft-union relations appear to cause the trouble.

REVIEW OF LITERATURE

In 1933, Hatton (2) reported differences in autumn leaf colouration and defoliation between pear trees on several clonal rootstocks and Chang (1) gave premature autumn leaf-colouration and defoliation as signs of incompatibility. Randhawa *et al.* (3) found that these abnormalities in the Kieffer pear are often related to obstructions and weakness at the graft-union, and are associated with small size and poor quality of fruit in the orchard.

MATERIALS AND METHODS

In the fall of 1939, in the Experiment Station nursery the two- and three-year pear trees showing early leaf-colouration were marked. Beside each one, a normal green-leaved tree of the same variety was also marked. These trees were planted in pairs in November. At the same time and in the same row four one-year Kieffer (P. *pyrifolia* × P. *communis*) pear trees on each of six Malling clones were planted. Trunk measurements, foliage colour in the fall, and yield and size of fruit have been recorded annually for all of these trees.

RESULTS

Seedling Rootstocks

Out of six pairs of trees, two red-leaved ones are dead, two are much dwarfed, one is slightly dwarfed, and the remaining one is very vigorous—a larger tree than its mate, the green-leaved one (Table 1). This very vigorous red-leaved tree was also well above the average size for the variety in the nursery row.

[1] Chief in Research.
[2] Assistant in Research.

Fruit production from these trees has been very meagre, mostly a result of poor pollination conditions. The trees which had red leaves in the nursery in the fall have not had red leaves every year in the orchard, nor have the trees green-leaved in the nursery consistently had green leaves in the orchard; but there has been a greater tendency to remain in the nursery classification than otherwise. Apparently seasonal conditions play a large part in determining autumn leaf colouration.

As already suggested for the Kieffer variety (3) it seems very likely that a high proportion of the *small* red-leaved pear trees in the nursery will turn out to be dwarfs in the orchard. About the *large* ones there appears to be some doubt. In Kieffer, the red-leaved trees are sometimes as prevalent as ten per cent of the nursery block but much less common in the other varieties, probably around one per cent on the average. In standard orchards these dwarf trees represent a direct loss but, if the graft-union is reasonably strong and the tree well anchored, the seedling stock might have possibilities as a dwarfing clone provided it could be propagated readily.

TABLE 1.—RELATION BETWEEN AUTUMNAL LEAF COLOUR IN THE NURSERY AND PERFORMANCE IN THE ORCHARD

Varieties†	Green-leaved trees, area of trunk cross-sec.		Red-leaved trees, area of trunk cross-sec.	
	Nov. 1939*	Nov. 1948	Nov. 1939*	Nov. 1948
	sq. cm.	sq. cm.	sq. cm.	sq. cm.
Bartlett‡	—	20.4	—	Dead
Ovid	4.9	64.2	4.5	Dead
Bartlett	1.5	45.8	1.8	14.3
Dean of Summer	3.1	94.2	1.8	50.9
Selection 140119	2.0	33.1	1.5	29.9
Doy. G. Boucher	2.0	42.8	4.5	69.2

† All on French pear seedlings.
* Time of planting in the orchard.
‡ Planted November, 1940; no size record at planting time.

Clonal Rootstocks

The differences in growth and fruiting of Kieffer on several Malling pear (Pyrus) rootstocks at the end of the ninth year in the orchard lend support to the conclusion reached in the test reported above, viz., that seedling roots may result in variable orchard trees. All of the Malling pear rootstocks were selected from seedling collections of European source (2). At East Malling at the end of the sixth year in the orchard, Dr. Jules Guyot on C7 rootstock had made more than double the growth made on C4 rootstock, these two representing the extremes among 13 clones.

Of the six Malling pear clones in this test at Vineland, two are very dwarfiing to the Kieffer variety, and depress the yield per tree considerably (Table 2). These trees would be considered quite undesirable for a standard orchard. At the end of nine years in the orchard the B1 rootstock has the highest yield but, year by year, C8 has had the best record on leaf-colour and fruit size. A more lengthy test with greater numbers of trees

and on various soil types will be necessary in order to give these rootstocks a proper rating. One of the two dwarfing rootstocks in this test, C3, proved to be incompatible with Dr. Jules Guyot in one test at the East Malling Station (2), but the other one, D3, gave trees of better than average vigour. On the other hand, B1, C8, and C4, which produced vigorous trees of Kieffer at Vineland, were among the four lowest in vigour rating at East Malling when the scion variety was Dr. Jules Guyot. This difference serves to point out the importance of testing new rootstocks with many varieties and under various climatic and soil conditions.

TABLE 2.—TREE-SIZE AND YIELD OF KIEFFER PEAR ON SEVERAL MALLING PEAR (PYRUS) ROOTSTOCKS

Rootstock	Number of trees	Area of trunk cross-section		Accumulated yield
		Nov. 1939*	Nov. 1948	
		sq. cm.	sq. cm.	kgm.
B3/1	4	1.4	55.5	16
B1	4	1.2	52.6	41
C8	4	1.3	45.8	29
C4	3‡	0.7	36.1	20
C3	4	1.0	8.1	5
D3	3†	1.2	6.4	5

* Time of planting in the orchard.
‡ A fourth tree was injured by an implement.
† A fourth tree died in 1941.

SUMMARY

The early colouration of pear leaves on individual trees in the nursery is probably an indication of uncongeniality between rootstock and scion. Planted in the orchard, such trees may soon die, they may be much dwarfed, or they may outgrow the trouble to become standard trees. Two out of six Malling pear clones have given very dwarf Kieffer pear trees.

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